What is claimed is:

Sub C1

1. An apparatus for measuring a surface profile of a target surface, comprising:

a light source configured to produce a light flux;

a light-flux optical system situated relative to the light source and the target surface and configured to (i) produce from the light flux a measurement-light flux and a reference-light flux, (ii) direct the measurement-light flux to the target surface so as to reflect from the target surface, (iii) provide the reference-light flux with a standard wavefront, and (iv) establish an interference between the reference-light flux and the measurement-light flux reflected from the target surface;

a phase-state changing device situated and configured to change a phase state of at least one of the reference-light flux and measurement-light flux relative to a standard;

a detector situated and configured to detect interference fringes produced by the interference at any of the various phase states; and

a computer connected to the detector and to the phase-state changing device, the computer being configured to produce, from the detected interference fringes produced at different respective phase states, data concerning respective phase distributions, and to calculate an average phase distribution.

2. The apparatus of claim 1, wherein the phase-state changing device is configured to change the phase state of the reference-light flux.

3. The apparatus of claim 1, wherein the phase-state changing device is configured to change the phase state of the measurement-light flux.

Sub C2

4. The apparatus of claim 1, wherein the phase-state changing device is configured to change the phase state of both the reference-light flux and the measurement-light flux a same amount relative to the standard, while maintaining a

constant phase difference between the reference-light flux and the measurement-light flux.

5. The apparatus of claim 1, further comprising a phase-modulation device situated and configured to produce a phase modulation of the measurement-light flux.

6. The apparatus of claim 1, further comprising a phase-modulation device situated and configured to produce a phase modulation of the reference-light flux.

7. The apparatus of claim 1, wherein:

the measurement-light flux has a frequency that is slightly different than a frequency of the reference-light flux; and

the interference is heterodyne interference.

8. The apparatus of claim 1, wherein the phase-state changing device is configured to change the phase state in respective increments, relative to the standard, of 0, $\pi/2$, π, and $3\pi/2$.

9. The apparatus of claim 1, wherein the phase-state changing device is configured to change the phase state in respective increments, relative to the standard, of 0, $\pi/4$, $\pi/2$, $3\pi/4$, π, $5\pi/4$, $3\pi/2$, and $7\pi/4$.

10. The apparatus of claim 1, wherein the phase-state changing device is configured to change the phase state in respective increments, relative to the standard, of from 0 to 2π and more than 2π as a whole.

11. An apparatus for measuring a wavefront aberration of a target object, comprising:

a light source configured to produce a light flux;

a light-flux optical system situated relative to the light source and the target object and configured to (i) produce from the light flux a measurement-light flux and a reference-light flux, (ii) direct the measurement-light flux to the target object so as to be transmitted through the target object, (iii) provide the reference-light flux with a standard wavefront, and (iv) establish an interference between the reference-light flux and the measurement-light flux transmitted by the target object;

a phase-state changing device situated and configured to change a phase state of at least one of the reference-light flux and measurement-light flux relative to a standard;

a detector situated and configured to detect interference fringes produced by the interference at any of the various phase states; and

a computer connected to the detector and the phase-state changing device, the computer being configured to produce, from the detected interference fringes produced at different respective phase states, data concerning respective phase distributions, and to calculate an average phase distribution.

12. The apparatus of claim 11, wherein the phase-state changing device is configured to change the phase state of the reference-light flux.

13. The apparatus of claim 11, wherein the phase-state changing device is configured to change the phase state of the measurement-light flux.

14. The apparatus of claim 11, wherein the phase-state changing device is configured to change the phase state of both the reference-light flux and the measurement-light flux a same amount relative to the standard, while maintaining a constant phase difference between the reference-light flux and the measurement-light flux.

15. The apparatus of claim 11, further comprising a phase-modulation device situated and configured to produce a phase modulation of the measurement-light flux.

16. The apparatus of claim 11, further comprising a phase-modulation device situated and configured to produce a phase modulation of the reference-light flux.

17. The apparatus of claim 11, wherein:

the measurement-light flux has a frequency that is slightly different than a frequency of the reference-light flux; and

the interference is heterodyne interference.

18. The apparatus of claim 11, wherein the phase-state changing device is configured to change the phase state in respective increments, relative to the standard, of 0, $\pi/2$, π, and $3\pi/2$.

19. The apparatus of claim 11, wherein the phase-state changing device is configured to change the phase state in respective increments, relative to the standard, of 0, $\pi/4$, $\pi/2$, $3\pi/4$, π, $5\pi/4$, $3\pi/2$, and $7\pi/4$.

20. The apparatus of claim 11, wherein the phase-state changing device is configured to change the phase state in respective irregular increments, relative to the standard, of from 0 to 2π and more than 2π as a whole.

Sub C4

21. A method for measuring a surface profile of a target surface of an object, comprising the steps:

(a) directing a measurement-light flux to the target surface so as to cause the measurement-light flux to reflect from the target surface;

(b) providing a reference-light flux having a standard wavefront produced by reflection from a standard surface;

(c) establishing a mutual interference between the reference-light flux and the measurement-light flux;

(d) detecting a respective phase-difference interference pattern produced by the interference;

(e) moving at least one of the target surface and the standard surface a respective specified distance from a respective standard position and then repeating steps (a)-(d), the respective specified distance being appropriate to change a phase state of the at least one of the light fluxes a specified amount;

(f) repeating step (e) to obtain respective phase-difference interference patterns at multiple phase states; and

(g) determining an average phase-difference distribution of the target surface from the respective phase-difference interference patterns obtained at the multiple phase states.

22. The method of claim 21, wherein step (e) comprises moving the standard surface.

23. The method of claim 21, wherein step (e) comprises moving the target surface.

24. The method of claim 21, wherein step (e) comprises moving both the target surface and the standard surface while maintaining a constant phase difference between the reference-light flux and the measurement-light flux.

25. The method of claim 21, wherein:

step (e) comprises moving the standard surface; and

step (d) is performed by phase-shift interference involving phase modulation of the measurement-light flux.

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26. The method of claim 21, wherein;

step (e) comprises moving the target surface; and

step (d) is performed by phase-shift interference involving phase modulation of the reference-light flux.

27. The method of claim 21, further comprising the step of providing the measurement-light flux with a frequency that is slightly different than a frequency of the reference-light flux so as to establish, in step (c), a heterodyne interference between the reference-light flux and the measurement-light flux.

28. The method of claim 21, wherein, in step (e), the at least one of the target surface and the standard surface is moved so as to change the phase state in a respective increment, relative to the standard, of 0, $\pi/2$, π, and $3\pi/2$.

29. The method of claim 21, wherein, in step (e), the at least one of the target surface and the standard surface is moved so as to change the phase state in a respective increment, relative to the standard, of 0, $\pi/4$, $\pi/2$, $3\pi/4$, π, $5\pi/4$, $3\pi/2$, and $7\pi/4$.

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30. The method of claim 21, wherein, in step (e), the at least one of the target surface and the standard surface is moved so as to change the phase state by one or more irregular increments, relative to the standard, of from 0 to 2π and more than 2π as a whole.

31. The method of claim 21, wherein the object is an optical element.

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32. An optical element, comprising a target surface having a surface profile measured using the method of claim 21.

33. A method for measuring a wavefront aberration of a target object, comprising the steps:

(a) directing a measurement-light flux to the target object so as to cause the measurement-light flux to be transmitted in a first direction through the target object to a reflection member;

(b) reflecting the measurement-light flux, that has been transmitted in a first direction through the target object, so as to cause the measurement-light flux to return through the target object in a second direction;

(c) providing a reference-light flux having a standard wavefront produced by reflection from a standard surface;

(d) establishing a mutual interference between the reference-light flux and the returning measurement-light flux;

(e) detecting a respective phase-difference interference pattern produced by the interference;

(f) moving at least one of (i) the reflection member and (ii) the standard surface a respective specified distance from a respective standard position and then repeating steps (a)-(e), the respective specified distance being appropriate to change a phase state of the at least one of the light fluxes a specified amount;

(g) repeating step (f) to obtain respective phase-difference interference patterns at multiple phase states; and

(h) determining an average phase-difference distribution of the target object from the respective phase-difference interference patterns obtained at the multiple phase states.

34. The method of claim 33, wherein step (b) comprises providing a mirror downstream of the target object so as to reflect the measurement light flux.

35. The method of claim 33, wherein step (f) comprises moving both the target object with reflection member and the standard surface while maintaining a

constant phase difference between the reference-light flux and the measurement-light flux.

36. The method of claim 33, wherein:
step (e) further comprises modulating the measurement-light flux; and
in step (d) the detected interference is a phase-shift interference.

37. The method of claim 33, wherein;
step (e) further comprises modulating the reference-light flux; and
in step (d) the detected interference is a phase-shift interference.

38. The method of claim 33, further comprising the step of providing the measurement-light flux with a frequency that is slightly different than a frequency of the reference-light flux so as to establish, in step (a), a heterodyne interference between the reference-light flux and the measurement-light flux.

39. The method of claim 33, wherein, in step (f), the at least one of the reflection member and the standard surface is moved so as to change the phase state in a respective increment, relative to the standard, of 0, $\pi/2$, π, and $3\pi/2$.

40. The method of claim 33, wherein, in step (f), the at least one of the reflection member and the standard surface is moved so as to change the phase state in a respective increment, relative to the standard, of 0, $\pi/4$, $\pi/2$, $3\pi/4$, π, $5\pi/4$, $3\pi/2$, and $7\pi/4$.

41. The method of claim 33, wherein, in step (f), the at least one of the reflection member and the standard surface is moved so as to change the phase state by one or more irregular increments, relative to the standard, of from 0 to 2π and more than 2π as a whole.

42. The method of claim 33, wherein the target object is a lens element.

43. A lens element, of which the wavefront aberration has been measured using the method of claim 33.

44. A projection lens system, comprising the lens element of claim 43.

45. A projection lens system, of which the wavefront aberration has been measured using the method of claim 33.

46. An apparatus for measuring an optical characteristic of a target object, comprising:

a light source configured to produce a light flux;

a light detector;

an optical system situated relative to the light source and the target object and configured to (i) produce from the light flux a measurement-light flux and a reference-light flux, (ii) direct the measurement-light flux to the target object so as to reflect from a target surface of the target object, (iii) provide the reference-light flux with a standard wavefront, (iv) establish an interference between the reference-light flux and the measurement-light flux from the target object; and (v) direct the interfering reference-light flux and measurement-light flux to the detector;

an actuator situated and configured to move at least one of the target object and the standard surface a respective specified distance relative to a respective standard location;

a phase-detection device connected to the detector and configured to detect respective phase differences in the detected light, at the various locations resulting from movement, achieved by the actuator, of the at least one of the target object and the standard surface over the respective specified distance; and

a computer configured to determine respective phase distributions from the respective phase differences and to calculate, from the respective phase

distributions, an average phase distribution, the average phase distribution corresponding to a measurement of the optical characteristic.

47. The apparatus of claim 46, wherein the optical characteristic is a surface profile of the target object.

48. The apparatus of claim 46, wherein the actuator is configured to move the target object relative to the respective standard location.

49. The apparatus of claim 46, wherein the actuator is configured to move the standard surface relative to the respective standard location.

50. The apparatus of claim 46, wherein the actuator is configured to move both the standard surface and the target object relative to the respective standard locations while maintaining a constant phase difference in the interfering reference-light flux and measurement-light flux.

51. An apparatus for measuring an optical characteristic of a target object, comprising:

a light source configured to produce a light flux;

a light detector;

an optical system situated relative to the light source and the target object and configured to (i) produce from the light flux a measurement-light flux and a reference-light flux, (ii) direct the measurement-light flux to the target object so as to pass through the target object, (iii) provide the reference-light flux with a standard wavefront, (iv) establish an interference between the reference-light flux and the measurement-light flux from the target object; and (v) direct the interfering reference-light flux and measurement-light flux to the detector;

a reflection member situated relative to the target object such that measurement light transmitted in a first direction through the target object reflects

from the reflection member and returns via a second direction, opposite the first direction, through the target object to interfere with the reference-light flux;

an actuator situated and configured to move at least one of the target object and the reflection member, and the standard surface, a respective specified distance relative to a respective standard location;

a phase-detection device connected to the detector and configured to detect respective phase differences in the detected light, at the various locations resulting from movement, achieved by the actuator, of the at least one of the target object and the reflection member, and the standard surface, over the respective specified distance; and

a computer configured to determine respective phase distributions from the respective phase differences and to calculate, from the respective phase distributions, an average phase distribution, the average phase distribution corresponding to a measurement of the optical characteristic.

52. The apparatus of claim 51, wherein the optical characteristic is a wavefront aberration of the target object.

53. The apparatus of claim 51, wherein the actuator is configured to move the target object, the reflection member, and the standard surface while maintaining a constant distance between the target object, the reflection member, and the standard surface.

54. The apparatus of claim 51, wherein the actuator is configured to move both the target object and the reflection member while maintaining a constant distance between the target object and the reflection member.

55. The apparatus of claim 51, wherein the actuator is configured to move the standard surface.

56. The apparatus of claim 46, wherein the target object is a lens element.

57. A lens element, of which the optical characteristic is a surface profile measured using an apparatus as recited in claim 46.

58. A projection lens system, comprising the lens element of claim 57.

59. A projection lens system, of which the optical characteristic is a surface profile measured using an apparatus as recited in claim 46.

60. The apparatus of claim 51, wherein the target object is a lens element.

61. A lens element, of which the optical characteristic is a wavefront aberration measured using an apparatus as recited in claim 51.

62. A projection lens system, comprising the lens element of claim 61.

63. A projection lens system, of which the optical characteristic is a wavefront aberration measured using an apparatus as recited in claim 51.